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Numerical Study on the Gas-Liquid Two Phase Flow in Pipeline Commissioning

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Abstract

Pipeline commissioning is a gas-liquid two phase flow process. In the hilly area, the complex flow status in pipeline may threaten the safety of the commissioning process. This paper developes a novel numerical technology to simulate the hydraulic process of pipeline commissioning. Several alternative modules are established, focused on which physical and mathematical models are established respectively to describe its flow status and corresponding pressure drop. With the aid of recognition technology and regulation and control technology, connection of these pipe sections can be performed to represent the actual pipeline and thus realizing the simulation of pipeline commissioning process.

Keywords

Pipeline Commissioning; Gas-liquid Two Phase Flow; Numerical Method; Simplified Model

Introduction

In recent years, with the rapid development of pipeline construction, the commissioning process has attracted more and more attention. Among all the commissioning methods, direct commissioning has become a mainstream method due to its time efficiency and low cost.(Nan Zhang et al. 2008, Zengqiang Zhang 2004, Shaoqing Li 2002, Guotai Shao et al. 2005)

In the process of direct commissioning, before the oil is filled into pipeline, a series of preparation work, such as hydraulic test and pipeline internal cleaning has to be performed. During the cleaning process, it is impossible to remove all water remained from hydraulic test. Therefore, gas-liquid two phase flow may occur in the subsequent pipeline operation. In the engineering practice, the terrain of the area where pipelines lays can be complex while the hydraulic characteristics, such as flow pattern, pressure drop and liquid holdup of pipeline in hilly area greatly differ from those of horizontal pipe. Thus, it is necessary to study the gas-liquid two phase flow in the commissioning processes of pipelines, especially on hilly areas.

In the commissioning process, field staffs most concern about the flow pattern and corresponding pressure drop in the pipeline. For the flow pattern, there have been some mature technologies, such as VOF (C.W. Hirt et al. 1981) method. However, very fine grid is indispensible in these methods which lead to relatively long calculation time and thus only fitting to the problem of small scale. As to the problem, this paper regards length of the pipeline that generally can reach hundreds of kilometers. If this kind of method is adopted, the calculation time and memory required are unacceptable. On the other hand, in the engineering practice, only the macro information such as pipeline inlet pressure and flow friction, rather than details such as breaking and coalescence behavior of bubbles is concerned. Thus, based on the constriction of computation condition and the requirement of engineering application, the numerical simulation of commissioning process aims at obtaining macro information of engineering guiding significance. Jing Gong et al. (1995) analyzed steady and transient flow characteristics of the long slop pipelines with the existence of partial flow based on fluid mechanics principles. Nan Zhang (2009) performed quasi-steady simulation of gas-liquid stratified flow in a declined pipe under constant flow rate based on non-wave model, drift-flow model and homogeneous flow model respectively. Boyi Liang (2011) used CFD software OLGA to establish a commissioning model under various conditions for comparison. However, to the best knowledge of the present authors, researches with the aim at commissioning process of hilly

pipeline are far from mature. Focused on this problem, this paper develops a novel simulation technology.

Physical and Mathematical Model

In the commissioning process, area terrain is the principal factor influencing its hydraulic process. Previous numerical experiments in which the charge-in process of local pipe sections was simulated indicated that different characteristics are shown when water front flows pipeline of different terrains. Therefore, it is necessary to establish models for the pipelines of different terrains respectively. Actual pipeline can be represented by the combination and connection of these basic pipe section modules.

Establishment of Basic Modules

To avoid the unnecessary troubles in programming, the interaction of modules should be as few as possible. Thus, the modules should be serializable, that is, the inlet boundary of every module should be full pipe flow-in. Based on this principle, the following 9 basic modules are determined.

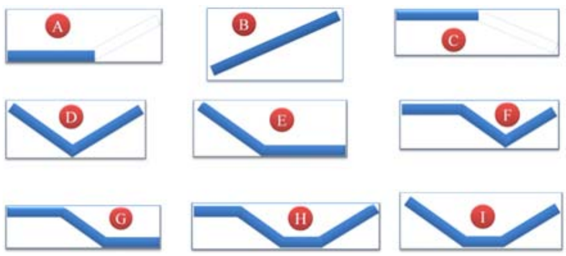

FIG. 1 SCHEMATIC OF BASIC MODULES

For the sake of brevity, only the mathematical model of D-type, F-type, H-type and I-type will be given concretely. In this kind of modules, huge stagnant air pockets may form in the declined pipe section. Once formation, these air pockets are continuously compressed during the commission process. Pressure of the air pocket may reach a high value and lead to local overpressure which is dangerous to the commissioning process. Thus, this kind of modules should be paid most attention. Due to the complexity of its terrain, the commissioning process of pipeline can be divided into several phases, among which the ones after air pockets forms are most critical and thus being emphatically discussed in the following.

Firstly, critical cleaning velocity is adopted to determine whether the air pocket would form or not. Only when the velocity of full pipe water front becomes greater than this velocity, would the stagnant air pocket form. Its value can be determined as Eq(1) shows.

$$v_c = \varsigma\sqrt{gD\sin\theta} \tag{1}$$

where g is gravity acceleration; D is pipeline diameter; θ is inclination of declined pipe section; ς is empirical coefficient, which should be determined by numerical experiment.

1) Situation Where Stagnant Air Pocket Would Form

Hydraulic parameters of air pocket meet the following relationship.

$$p_a V_a = const_1 \tag{2}$$

where p_a and V_a represent the pressure and volume of the air pocket, respectively; $const_1$ is determined by the initial volume of the air pocket.

Hydraulic parameters of the liquid slug at the bottom of the module meet the following relationship.

$$(p_a - p_e)A - L_s \cdot \pi D \cdot \tau - \rho A g(h_2 - h_1) = 0 \tag{3}$$

where A is pipe section area; τ is friction force per unit area; p_e is pressure at the pipeline end; L_s is length of the liquid slug; h_1 and h_2 are liquid height of the closed side and open side respectively.

Meanwhile, geometrical parameters should satisfy the following relationship.

$$\frac{\partial h_1}{\partial t}A(1-\phi_a) + \frac{\partial h_2}{\partial t}A = Q \tag{4}$$

where Q is volume flow rate; ϕ_a is liquid holdup in the declined pipe section.

With Eq(2), Eq(3) and Eq(4), combining the following geometrical relationship, flow status in the pipeline can be solved.

$$V_a = \left(L_{dec} - \frac{h_1}{\sin\theta_1}\right)A(1-\phi_a) \tag{5}$$

$$L_s = \frac{h_1}{\sin\theta_1} + \frac{h_2}{\sin\theta_2} + L_{hor} \tag{6}$$

where L_{dec} and L_{hor} are length of declined pipe section and bottom horizontal pipe section respectively. As to D-type and F-type pipe section, $L_{hor} = 0$.

2) Situation Where Air Pocket Would Not Form

In this situation, head of the air pocket flows down with liquid flow while gas of the air pocket is continuously discharged at the bottom. Firstly, slip ratio γ of the air pocket head is defined as following

$$\gamma = \frac{v_h}{v_f} \quad (7)$$

where v_h is the velocity of bubble head; v_f is the full pipe flow velocity; γ can be determined by numerical experiment.

Hydraulic parameters of air pocket meet the following relationship.

$$\frac{p_a V_a}{m_a} = const_2 \quad (8)$$

where m_a is air pocket mass; $const_2$ is determined by the initial state of air pocket.

Air pocket volume is determined by the following equation.

$$V_a^n = V_a^{n-1} - v_h^{n-1} A\left(1-\phi_a\right)\cdot \Delta t \quad (9)$$

What needs to be notified is that coefficient γ is relevant to air pocket pressure and thus time-dependent.

Air pocket mass is determined by the following equation.

$$m_a^n = m_a^{n-1} - \rho_a^{n-1}\left(V_a^n - V_a^{n-1}\right) \quad (10)$$

where ρ_a^{n-1}, the gas density in the air pocket at last step, can be determined by the following equation.

$$\rho_a^{n-1} = \frac{m_a^{n-1}}{V_a^{n-1}} \quad (11)$$

Solving the above equations simultaneously, the simulation of hydraulic status of this situation can be performed.

Connection of the Modules

In Section 2.1, physical and mathematical models of the modules are introduced. In the following, the approach to perform the connection of these 'basic elements' to represent the actual pipeline will be discussed. To improve the versatility, the connection approach should solve the following problems.

(1)Automatic recognition can be performed with pipeline route profile to determine the connection sequence of referred modules;

(2)A module may occur repeatedly;

(3)As to the modules where air pocket may form, such as D-type and H-type, their hydraulic status is independent of that of the subsequent pipe sections.

Focused on these problems, a program flow is designed. For convenience, after the division of the whole pipeline by recognition module, along the direction from inlet to outlet, the pipe sections are named 1#, 2#, 3# and so on.

Due to the interaction between pipe sections, every pipe section should be incorporated in the whole simulation process other than simulated respectively and then composited. Therefore, every module is designed to be of the following structure: called each time, the simulation is performed forward for a single time step. By this, the modules can be serialized and timely perform the data transmission and feedback.

During the simulation process, the following details are noteworthy. Firstly, calculation of a module should be just started when full pipe flow water front reaches its inlet. Thus, the obtained hydraulic status of every module should be fed back to the regulation and control module to judge which module should be started in the next time step. Secondly, since the call of every modules is not continuous, the obtained data recording the hydraulic status should be temporarily stored into a data storage. This data would be used as calculation condition and input to the 'calculator' in the next time step when this module is called again. Meanwhile, every module may appear multiple times in a pipeline and thus multiple data storage should be set up to store the corresponding data obtained in different locations of the same module to avoid the confusion in data transmission.

For the modules where air pockets may form, their hydraulic status is dependent on that of subsequent pipe sections. Thus, their locations should be recorded so that the hydraulic status of subsequent pipe sections can be timely fed back to corresponding pipe sections in the regulation and control module.

With this approach, the above-mentioned requirement can be satisfied. And the basic modules can be correctly connected.

Example and Analysis

Hereinbefore, the technology this paper develops to simulate the commissioning process of pipeline on the area of complex terrain is described. Since the study of this technology is still at the beginning, only a simplified pipeline is considered and analyzed here, whose pipeline route profile is as shown in Fig. 2 while pipeline diameter is 0.813 m and charge-in water flow rate is 1500 kg/s.

In this example, the pipeline can be divided into 4 sections which correspond to the B-type, D-type, A-type and B-type, respectively. Based on this,

simulation of its commissioning process is performed. The obtained changing trend of pressure drop is as Fig. 3 shows.

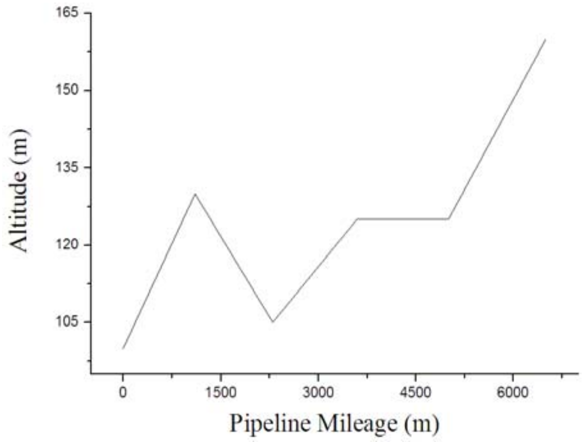

FIG. 2 PIPELINE ROUTE PROFILE

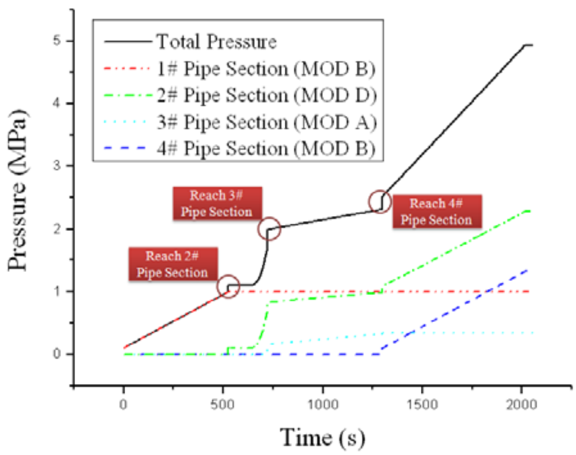

FIG. 3 PRESSURE DROP

It can be seen from Fig. 3 that except for 2# section, the pressure drop of every pipe section only changes when the full pipe flow water front is in it, indicating that its hydraulic status is independent of subsequent sections. As to the 2# section, due to the stagnant air pocket, although full pipe flow water front has passed this section, air pocket still suffers compression, resulting in extra pressure loss, which makes the pressure drop in this pipe section continuously increase. Calculation results show that the extra pressure loss caused by air pocket accounts for about 35% of the total pressure drop of the pipeline.

It can be indicated from the above analysis that the results obtained by this technology are basically reasonable. Meanwhile, with this technology, the calculation time for this simulation example required by ordinary PC is 310 s, which satisfies the engineering requirement.

Summary

This paper develops a novel technology to simulate the pipeline commissioning process. Several alternative modules are established, focused on which physical and mathematical models are established respectively to describe its flow status and corresponding pressure drop. With recognition technology, actual pipeline is divided into several pipe sections matching the corresponding alternative modules. Regulation and control technology are further used to perform the connection of these pipe sections to represent the actual pipeline and thus realizing the simulation of pipeline commissioning process.

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